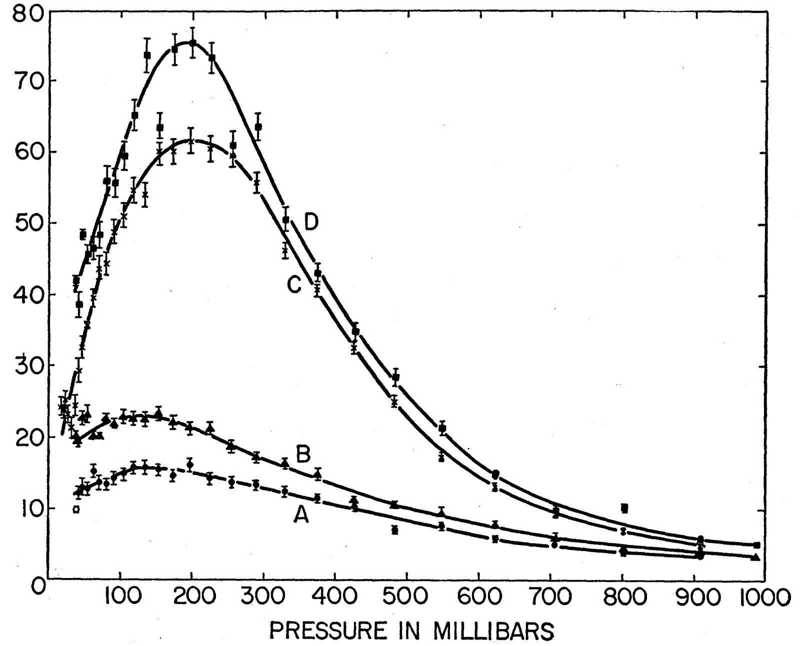

FIG. 1. Vertical intensity of cosmic radiation penetrating 10 cm of lead. A: at Bangalore 3°N (mag), B: at Delhi 19°N (mag). Total vertical intensity of cosmic radiation, C: at Bangalore 3°N (mag), D: at Delhi 19°N (mag).

The intensity of the component penetrating 10 cm of lead absorber at 3°N and 19°N increases continuously with decreasing pressure, reaches a maximum at a pressure of 120 millibars, and then falls with further decrease in pressure. However, the slopes of curves A and B on either side of the maxima differ from each other. The rise of curve B with decreasing pressure before the maximum is much faster than that of curve A, whereas the fall after the maximum is much less steep.

The total intensity at 3°N and 19°N (curves C and D) increases rapidly with decreasing pressure passes through a maximum at 200 millibars and then decreases very rapidly up to the lowest pressure obtained.

There is no detectable shift in position of the maxima between 3°N and 19°N, both in the case of the total intensity and the penetrating component. This may be due to the smallness in difference in the cut-off values of the primary radiation at the two latitudes.

Neher and Pickering[2] reported that there was no detectable increase in the total intensity of cosmic radiation at high altitudes in going from 3°N to 19°N, but our results are in disagreement with this and show that the ratio of the intensities is given by $I_t(19°)/I_t(3°)=1.22$ at the maximum. For the penetrating component at the maximum, the corresponding ratio $I_p(19°)/I_p(3°)$ is 1.46. The latitude effects $I_{19°}/I_{3°}$ for the total radiation and the penetrating component decrease with increasing pressure. The latitude effect at the maximum is much greater for the penetrating component than for the total cosmic radiation as the above figures show, whereas Vidale and Schein[3] found that at 28°, 41°, and 55° the latitude effect for the total intensity was higher than that of the penetrating component.

The primary flux values obtained by extrapolation of the penetrating component curves, uncorrected for showers and accidentals, to the top of the atmosphere at 3°N and 19°N along 77°E geographic longitude are 227 and 364 particles meter$^{-2}$ sterad$^{-1}$ sec$^{-1}$, respectively. If the correction due to showers and accidentals, which is essential, is considered, the flux values may be smaller by 25 to 30 percent. The shower and accidental measurements have been made, but they are not used to correct the flux values as they do not extend below 75 millibars.

The theoretical analysis of these results, which is in progress, will be published soon.

We wish to express our gratitude to the Atomic Energy Commission, Government of India, for the grants which have made these experiments possible. We wish to express our thanks to Professor H. J. Bhabha for his great interest in the progress of the work and for helpful suggestions and criticism.

[1] Curve A, which has already been published [Phys. Rev. **83**, 173 (1951)], is given here for comparison with the results at 19°N (mag).

[2] H. V. Neher and W. H. Pickering, Phys. Rev. **61**, 407 (1942).

[3] M. Vidale and M. Schein, Phys. Rev. **81**, 1065 (1951).

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# Measurements of Meson Masses and Related Quantities

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A MESON-MASS measurement program has been completed. The method has been partially described[1,2] and preliminary results[2–4] have been reported at earlier stages of the work. As noted previously,[2] it was discovered that stray mesons coming from points other than the target were interfering with the measurements. Attempts to reduce this effect have been successful, and little evidence of stray mesons remains.

To determine the pion masses, meson and proton ranges and momenta were measured in the same velocity interval. To measure the pion-to-muon mass ratio, similar comparisons were made between pions and muons. In one of the methods employed to find the momentum $p_0$ of the muon which is emitted when the pion decays at rest, the muon range is compared with the ranges of pions of known momentum and of nearly the same velocity. The decay muons were also compared directly with muons coming from the target in a second type of experiment.

For each particle, the quantity studied statistically is that function of the mass in which the range appears linearly. The dominant term in the variance of this quantity is the range straggling; consequently, it as well as other sources of variance has been examined closely, and the shapes of the measured distribution functions are now understood theoretically.

The stray mesons mentioned above introduced a systematic error of about one percent in the mass values quoted previously. The known systematic effects are now believed to be eliminated,

TABLE I. Values for meson masses and related quantities. The errors quoted are statistical probable errors. The uncertainties in the various quantities are not independent. The mass assumed for the proton is 1836.1 electron masses.

| | | |
|---|---|---|
| Fundamental mass ratios | | |
| $\pi^+$/proton | $\pi^-$/proton | $\pi^+/\mu^+$ |
| $0.14888 \pm 0.00011$ | $0.14840 \pm 0.00017$ | $1.321 \pm 0.002$ |
| Absolute decay momentum of positive muon | | |
| $p_0 = 29.80 \pm 0.04$ Mev/$c$ | | |
| Derived masses in units of the electron mass | | |
| $\pi^+$ | $\pi^-$ | $\mu^+$ |
| $273.4 \pm 0.2$ | $272.5 \pm 0.3$ | $207.0 \pm 0.4$ |
| Absolute mass measurements in units of the electron mass[a] | | |
| $\pi^+$ | $\mu^+$ | $\pi^+ - \mu^+$ |
| $(273.5 \pm 1.2)$ | $(207.1 \pm 1.1)$ | $(66.41 \pm 0.07)$ |

[a] The bracketed numbers are absolute mass determinations in the derivation of which no use is made of information obtained from the direct comparison of masses with that of the proton, but it is assumed that a neutrino of zero rest mass is emitted in a two-body decay of the pion.

and the statistical errors also have been considerably reduced. Our final results are contained in Table I.

The measured $\pi^+$ and $\pi^-$ masses differ by an amount which is almost significant. If this difference is assumed to be real, an alternative to a true difference between the pion masses is a difference in the stopping cross sections for the positive and negative pions.

Taking the muon/electron mass ratio to be 207, the value of $p_0$ found implies that the kinetic energy of the muon is 4.12 Mev.

Complete reports of the theoretical and experimental details are being prepared for publication.

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## Origin of Cosmic Rays

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THE most popular class of theories of the origin of cosmic rays supposes that charged particles are accelerated by the electric fields associated with temporally varying magnetic fields. In a broad sense the whole of this class might be called "betatron processes," but there is one subclass[1,2] which resembles the betatron much more closely than the others. The intention here is to point out certain difficulties for this subclass, which have not received sufficient attention, and to survey the other possibilities.

Although magnetic fields which vary with time are observed on the sun and certain stars, it does not follow that "betatron processes" in the narrow sense must occur, but only in the broad sense. Remembering that the magnetic fields are nonuniform in space, the temporal variation of the magnetic field could in principle be the result of a uniform motion of the magnetic field. A Lorentz transformation shows that this case will not account for any cosmic rays.

Riddiford and Butler[2] consider a uniform magnetic field increasing in time, and then the lines of force of the electric field are concentric circles. Consider the case in which the change of the field is very slow compared with the Larmor frequency. The perturbation method[3] may then be used, and it is found that the motion of any charged particle averaged over a Larmor period is given as follows. The average distance of the particle from the the axis where **E** vanishes is proportional to $H^{-\frac{1}{2}}$; the average relativistic momentum perpendicular to **H** is proportional to $H^{\frac{1}{2}}$. This result is just the same as though the particles were contained in a box, and the box were compressed in directions perpendicular to **H** but not parallel to **H**. The question of what causes this compression has not been answered, and it is not plausible that this process should occur on stars with a compression factor sufficient to generate cosmic rays.

The perturbation method is valid in practice except for very weak fields. This case is restricted, however, by a condition $E < vH/c$, where $v$ is of the order of the velocity of mass motion of the gas. This condition is true unless there is a large current density and unless high frequency oscillations occur. If then the perturbation method is in error by a substantial factor, the field cannot extend over a distance much greater than $mcv/eH$, which is the radius of the orbit of a particle with velocity $v$. Consequently the highest energy obtained is not many times $mv^2$.

Investigation of the case when there is a large current density leads to the conclusion that cosmic-ray energies can be attained near a neutral point of the magnetic field.[4,5]

The theory of high frequency oscillations in ionized gases is not far enough advanced to allow the possibility of acceleration by high frequency fields to be discussed.

The general theory of the orbits of particles in magnetic fields ln nonuniform motion involves combinations of the special cases discussed here. Fermi[6] has discussed the case of turbulent motion and shown that the particles have a slow average gain of energy.

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## Fluorescent Light Yields with Alpha, Beta, and Gamma Radiations*

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THE absolute light yields of various fluorescent materials under high-energy excitation have been investigated previously.[1–3] Recently Bril and Klasens[4] have reported many new results for 20-kev electron excitation. It must be borne in mind that there is a marked decrease in the efficiency of light output with excitation by highly energizing particles for most of the materials except ZnS and CdS. If this is taken into account, the results of Bril and Klasens confirm most of the earlier results in those cases where the same materials were investigated. (The measurements of Bril and Klasens were made with rather highly energizing 20-kev electrons.) Since it has frequently been contended that even traces of impurities, especially with organic substances, influence the fluorescent yield considerably, new measurements of relative efficiencies with pure materials have been made and are presented in Table I. Hard gamma rays from radium, beta particles from Sr 90, and alpha particles from Po were used on all the solid materials. For electrons the values have been adjusted for equal stopping power, and for gamma rays the values were reduced to equal masses; no corrections were made for alpha particles since they were completely absorbed in the materials used. The difference in spectral sensitivity of the 1P28 multiplier for the various materials has not been taken into account. This is serious only for the Radelin powder emitting in the green; if spectral corrections were applied for this material, the values would be close to those of the ZnS (type D, Dupont).

Thin layers of powders, crystals, or liquids were used (of the order of 10 mg/cm²). No appreciable loss was found in ZnS on account of true absorption in the powder caused by lengthening of the light path by multiple scattering, since the light output was found to be proportional to the thickness of the powder over a considerable range when electrons and gamma rays were used. Anthracene, which also showed no self-absorption in these thicknesses, was tested both as a powder and as a clear transparent